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A small mission concept to the Sun–Earth Lagrangian L5 point for innovative solar, heliospheric and space weather science

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ABSTRACT

We present a concept for a small mission to the Sun–Earth Lagrangian L5 point for innovative solar, heliospheric and space weather science. The proposed INvestigation of Solar-Terrestrial Activity aNd Transients (INSTANT) mission is designed to identify how solar coronal magnetic fields drive eruptions, mass transport and particle acceleration that impact the Earth and the heliosphere. INSTANT is the first mission designed to (1) obtain measurements of coronal magnetic fields from space and (2) determine coronal mass ejection (CME) kinematics with unparalleled accuracy. Thanks to innovative instrumentation at a

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vantage point that provides the most suitable perspective view of the Sun–Earth system, INSTANT would uniquely track the whole chain of fundamental processes driving space weather at Earth. We present the science requirements, payload and mission profile that fulfill ambitious science objectives within small mission programmatic boundary conditions.

1. Introduction

Coronal mass ejections (CMEs) are massive expulsions of plasma and magnetic flux from the solar corona into interplanetary space with speeds ranging from 200 to 3000 km/s. The occurrence rate of CMEs varies with the solar cycle, from 1 per day at solar minimum to 5 per day on average during solar maximum (e.g., Webb and Howard, 2012; and references therein). CMEs are recognized as the main drivers of detrimental space weather effects at Earth and in the heliosphere. They are the main cause of major geomagnetic storms resulting in large ionospheric and ground-induced currents which can disrupt satellite operations, navigation systems, radio communications and ground power grids (e.g., Schrijver et al., 2015). Moreover, together with large flares, they are responsible for the most intense solar energetic particle events, which can endanger life and disrupt technology on the Earth and in space (e.g., Reid, 1986). The motivation of the INSTANT mission concept arises from a basic fact: our current inability to understand how and when a CME will erupt, whether or not a CME has any chance of impacting the Earth, and to what degree it can disturb the near-Earth space environment. The INSTANT design is based on the realization that some of these open questions can be resolved within a small mission programmatic constraint, with innovative observations from a vantage point that provides a comprehensive view of (1) the processes at the Sun known to drive severe space weather at Earth and (2) the region of space between the Sun and the Earth (cf. Fig. 1).

Interest in observing solar-terrestrial phenomena from the Lagrangian L4 and L5 points comes from the suitability of these locations for tracking disturbances that propagate towards the Earth. The only mission that has actually performed measurements from these locations was NASA's STEREO mission (Kaiser et al., 2008), comprising two identical spacecraft drifting ahead of and behind the Earth on similar orbits around the Sun. These spacecraft only drifted through the L4 and L5 points, and did not station-keep there for continuous observations of Earth-impacting transients.

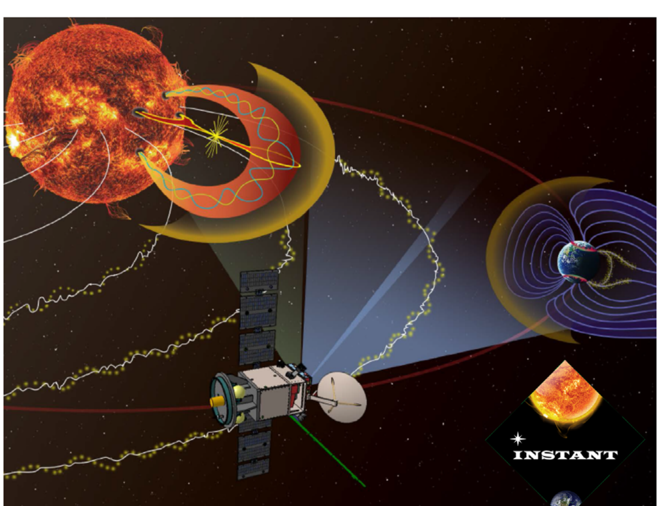

Fig. 1. Artistic view of the INSTANT mission concept.

Despite this, the STEREO mission paved the way for future L5/L4 dedicated missions. It demonstrated the capability of wide-angle, white-light imaging (Heliospheric Imagers; HI; Eyles et al., 2009) to track density disturbances from Thomson scattering off heliospheric electrons all the way from the Sun to the Earth, as well as other space weather capabilities (e.g., Simunac et al., 2009; Webb et al., 2010). Both L4 and L5 are good locations for tracking Earth-bound CMEs. However, as further detailed throughout the paper, for a single spacecraft mission the L5 location is more appropriate as it provides early observation of active regions, coronal holes and corotating interaction regions owing to solar rotation.

Other L5 mission concepts have been suggested and proposed in the recent past, but with different focus owing to different instrumentation and programmatic constraints. We note in particular the early concept summarized in Schmidt and Bothmer (1996), and which was submitted to the ESA medium class mission call in 1993. The concept resembled INSTANT in that it had a limited payload budget, albeit with different instrumentation, science goals and mission profile. A small mission concept was also presented in Akioka et al. (2005), focusing primarily on ways to achieve wide-angle interplanetary imaging and efficient on-board data processing (given the limited telemetry available from L5).

Larger L5 mission concepts have been proposed more recently, with in particular the Earth-Affecting Solar Causes Observatory (EASCO; Gopalswamy et al., 2011a, 2011b). This mission concept proposes to fill the gaps in observational capabilities of past missions (e.g., SOHO and STEREO), with key additional measurements such as radio, magnetograph and X-ray imaging. EASCO was studied in detail by NASA, including the full mission profile that differs greatly from that of INSTANT owing to EASCO's much broader payload. Strugarek et al. (2015) also recently proposed a large mission concept for both space weather science and operational purposes, with two spacecraft separated by 34° east and west from the Earth on its orbit for stereoscopic imaging of Earth-bound disturbances. The importance of an L5 mission for space weather purposes was recently presented by Vourlidas (2015), as well as in the COSPAR and ILWS roadmap (Schrijver et al., 2015).

With INSTANT, we propose a specific L5 mission concept focused primarily on science, with innovative instrumentation on board a small platform, and with an efficient mission profile to comply with a small mission opportunity. The baseline payload consists of 5 complementary instruments. The MAGIC (MAGnetic Imager of the Corona) coronagraph would for the first time provide measurements from space of the coronal magnetic field from 1.15 to 3 solar radii (R_S), using polarization measurements in the Lyman-α line (through the Hanle effect). It also would obtain white-light imaging. The Polarizing HELiospheric Imager eXplorer (PHELIX) performs wide-angle (out to 70° elongation from Sun center) imaging in the white-light domain with unprecedented polarization capabilities. The baseline payload also comprises a set of three complementary in-situ instruments, with an associated In-situ Data Processing Unit (IDPU): MAG (MAGnetometer), PAS (Proton and Alpha Sensor) and HEPS (High Energy Particle Sensor).

2. Science objectives

The science objectives of the INSTANT mission concept are summarized in Table 1, and detailed science argumentation for